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Military vehicle parts and assemblies are subject to battlefield damage and overextended usage. Immediate recovery, from remote locations, of vehicles having damaged components may not be possible through current channels. Nonconventional future battle scenarios will require versatile rebuilding equipment units, novel and standard stock materials and unique processes at the site of disability. Results from the Phase I effort indicate a need for and the feasibility of developing critical part design modifications and assembling the equipment needed for salvage and field remanufacture of damaged components. The Phase I effort demonstrates novel remanufacturing capabilities and provides for the potential commercialization of transportable, multifunctional equipment units for battlefield or remote site availability and use. A transportable prototype field manufacturing unit with remote roving capability has been investigated and will be assembled by Mission Research Corporation (MRC) during a Phase II effort for use on battle-damage vehicle parts. Keywords:

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SUMMARY

Military vehicle parts and assemblies are subject to battlefield damage and overextended usage. Immediate recovery, from remote locations, of vehicles having damaged components may not be possible through current channels. Field repairs are accomplished by Battlefield Damage Assessment and Repair (BDAR) manuals and procedures. Transportable remanufacturing capability is possible which includes material, process, and machining specification additions or modifications to the field manuals. Nonconventional future battle scenarios will require versatile rebuilding equipment units, novel and standard stock materials and unique processes at the site of disability. Remanufacturing procedures for the susceptible parts critical to the mobility of the vehicle and having a high damage failure rate determined in the field exercise in Meppen, Germany will identify and help select the equipment required to support recovery. A transportable prototype manufacturing unit with remote roving capability will be assembled by Mission Research Corporation (MRC) during the Phase II effort and used on damaged vehicle parts. Results from the Phase I effort indicate a need for and the feasibility of developing critical part design modifications and assembling the equipment needed for salvage and field remanufacture of damaged components. The Phase I effort demonstrates novel remanufacturing capabilities and provides for the potential commercialization of transportable, multifunctional equipment units for battlefield or remote site availability and use. Army mechanics and tank personnel will benefit from this additional repair capability.

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Preface

The authors gratefully acknowledge the contributions of several individuals who have provided assistance or input to this project. In particular, appreciation is expressed to Mr. Roger Smith, U.S. Army Tank-Automotive Command (TACOM), who served as technical monitor and provided information on part details as well as names and sources of information on parts, and components, failure and criticality data. Other individuals who have contributed to this research effort include: Mr. Larry Bain, Army Maintenance System Analysis Group (AMSA) of the U.S. Army Aberdeen Proving Grounds (APG); Mr. Clark Fox, Section Chief of the Maintenance Data Analysis Base, APG; Mr. Dan Kirk, Ground Vehicle Vulnerability Records Group of the U.S. Army Ballistic Research Laboratory; and Mr. Robert Shumacher of the Sustainability Predictions for Army Spare Components group of APG.

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1.0. INTRODUCTION

This research effort, funded by the U.S. Army Tank - Automotive Command (TACOM) Research, Development and Engineering Center under contract Number DAAE07-87-C-R064, dealt with the feasibility of using portable field remanufacture units to repair damages on battle vehicles. The Army is interested in the recovery of personnel and damaged vehicles during combat situations. Mission Research Corporation (MRC) responded with a Phase I Small Business Innovative Research (SBIR) proposal to determine the feasibility of remanufacturing Army vehicle parts in the field.

This research effort began with a familiarization of the Army vehicles used in combat arena's and the parts susceptible to battlefield damage, including the review of frequency of failure (FF) records. The FF data was found limited for this study. Information provided by Sustainability Predictions for Army spare components Required for Combat (SPARC) records were for failed noncombat or lost parts. The SPARC computer data shows peacetime part replacement and maintenance records, with very little separate data on actual field damage. Although the Israeli war vehicles (post WWII) have appreciable critical part combat damage information, there is no data on authorized damaged part rebuilding in remote locations. There are some reports on unauthorized repair with limited resources and repair directed by authorized Battle Damage Assessment and Repair (BDAR) procedure guidelines. Finally, some records are kept which are essential for decreasing supply line demands during critical and increased combat activity.

Results of the MRC Phase I study indicate that additional remote recovery or rebuilding of vehicle parts, including performance behind enemy lines, is critically needed. The MRC research effort has focused on the feasibility of providing mobile remote remanufacturing capabilities. The need for mobility and survivability of the repair vehicle has also been established.

The Phase I final task objective was the selection of equipment and vehicles available to fill the above needs. The performance of the Phase I effort included equipment selection and use of existing Army vehicles for the remanufacturing/repair capability. An assessment of existing vehicle capabilities was made from vehicle characteristic sheets received from the contract technical monitor, Roger Smith, of TACOM.

In estimating the technical feasibility of mobile remote remanufacturing capability it is clear that the entire tank vehicle is not to be remade in the field. However by focusing on the parts critical to the mobility or operation of the defense vehicle it was possible to narrow down the required remanufacturing equipment needed to return the tank, etc., to more friendly sites where standard maintenance procedures can complete the repairs.

2.0. OBJECTIVES

2.1. Phase I Objectives

The originally proposed technical objective was to define the critical parts of disabled Army vehicles, the materials and processes required for replacing them, and the portable units and rebuilding systems needed to remanufacture in remote locations.

The contract primary objective as stated is: "To determine the feasibility of forming a portable field remanufacturing assembly to repair or replace vehicular components or assemblies damaged by combat, terrain and/or wear."

Shown below are the program goals and Phase I objectives which were redefined at a kickoff meeting held 5 August 1987 in Warren, Michigan. All goals and objectives lead to a Phase II development effort to assemble prototype field remanufacturing capability units.

The program goals are as follows:

- Develop transportable field remanufacturing units for damaged Army vehicle components.
- Assemble the design/material modifications and equipment for the repairs.
- Maintain flexibility in program objectives to fulfill developing Army combat conditions.

The Phase I objectives are as follows:

- Determine the feasibility of a transportable manufacturing capability for rebuilding parts at remote sites.
- Locate and review parts and assemblies subject to battlefield damage/failure and critical to the mobility of Army vehicles.
- Modify material/component design of the damaged component for remanufacture in the field.
- Identify the shop equipment needed to accomplish the rebuilding of parts.
- Describe the vehicles for transporting the equipment necessary for mobile repair.

2.2. Phase I Proposal Task Schedule

The Phase I efforts proposed were managed and conducted by MRC at the Survivable Structures Technologies Division located in Costa Mesa, California.

Table 2-1 shows the six tasks that were proposed and completed during the 6-month Phase I effort. The final report was delivered 1 month after completion of the technical effort (February 1988). Table 2-2 shows the task plan of the Phase I proposal.

2.3. Contract Scope of Work and Research Conducted in Phase I

The Phase I contract scope of work is explained in Table 2-3. The contract task numbers and descriptions are formatted to show the effort provided in Phase I. Figure 2-1 illustrates the time schedule used for the various tasks of this Phase I study.

The research effort consisted of identifying key vehicles and reviewing assembly drawings and blueprints of component parts, 1/32 scale model parts, identification of parts critical for mobility, and the frequency of failure from SPARC lists for key components and assemblies identified above.

The equipment and additional vehicle types applicable to the remanufacturing of tank parts were reviewed for use in the development effort. The process, approximate weight and size, and the cost of each repair machine or item is presented in par. 3.0 of this report. In addition, vehicles were rated for use as remanufacture capacity and mobility in remote areas. This data is reviewed in par. 3.2.4.

Finite element analysis of failure modes in a critical tank part (i.e., wheel arm) were performed. A field remanufacture process was established and applied to the most likely failure mode of the above part. Novel material replacement and remanufacture processes were used in this phase of the study to show feasibility of field remanufacturing using alternate materials and redesign concepts.

2.4 Technical Approach and Methods Used to Achieve Objectives

The Phase I study focused on battlefield damage repair for the M60 and M113 family of Army vehicles. The technical approaches used in this study can be divided into five categories: 1) Identification of critical components through fault tree analysis and review of field data; 2) Identification of failure modes in critical components through analysis such as finite-element methods; 3) Assessment of repair methods for field remanufacture; 4) Identification of tools, materials and repair/remanufacture equipment; and, 5) Development of feasible mobile remanufacture system to achieve field repair even behind enemy lines.

Table 2-1. Phase I Proposed Task Schedule

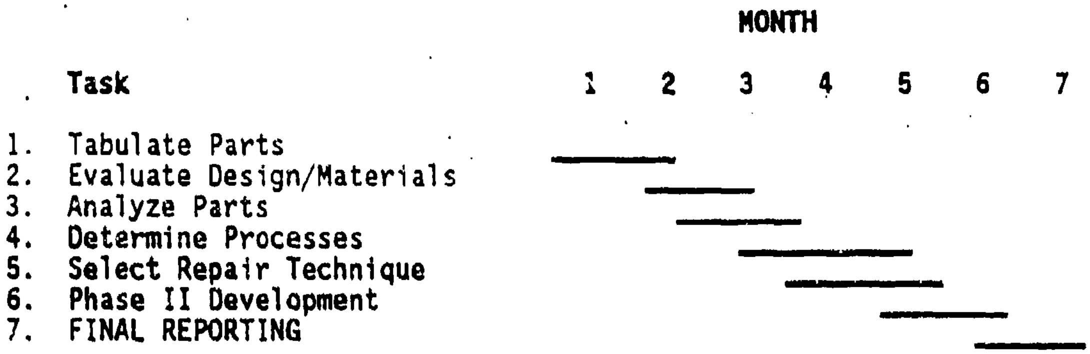


Table 2-2. Phase I Tasks

Task 1 - Tabulate Parts and Materials - In this Task, MRC collected information on the materials and parts susceptible to damage or breakdown, rated the criticality of the parts, and defined the possibilities of rebuilding in field condition environments.

Task 2 - Design Evaluation - MRC conducted an investigation of the design and possibility of material substitution of various tank components. In this task MRC determine the feasibility of remanufacturing certain key components. Mechanical and design engineers were used for identifying the required loads, tolerances, stress factors and specifications of selected components.

Task 3 - Failure Analysis of Failed Parts - MRC analyzed parts selected in Task 2 for further study. Discuss the failure modes and material properties.

Task 4 - Replacement Process Determination - MRC used a computerize the filing system and determine the processes available to replace the critical parts identified.

Task 5 - Repair Technique Rebuild System - Select and describe the supplies and materials that comprise the rebuild system. The processes determined in Task 4 were used in remanufacturing parts.

Task 6 - Phase II PLAN - Formulate a "repairing of Army parts proposal" and select equipment and define machines available and transportable on tracked or wheeled vehicles.

Final Reporting - The final report is to be submitted to the contracting agency within 30 days after completion of the Phase I effort, and will comply with the reporting conditions required by the SBIR solicitation for Phase I.

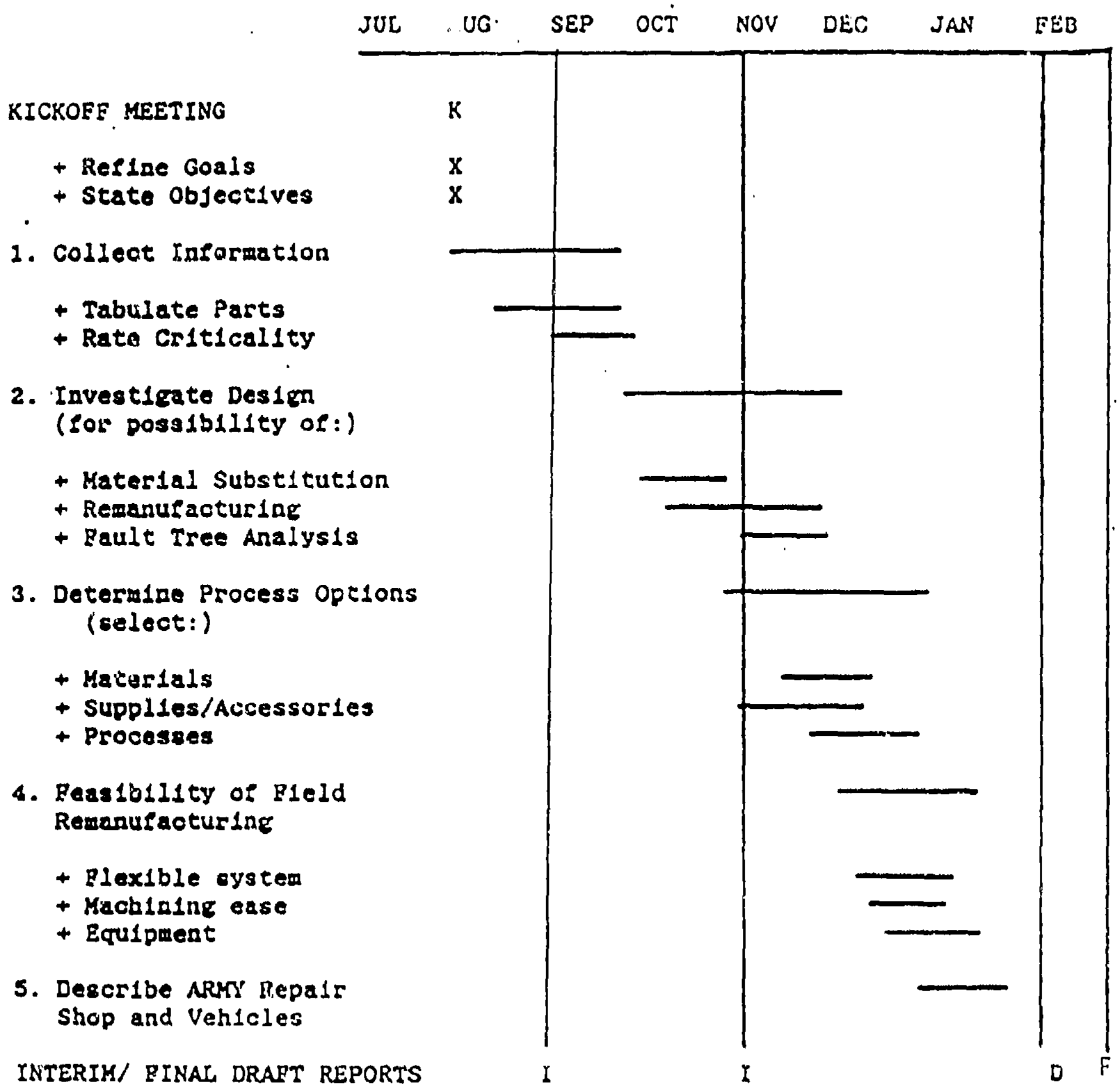


Figure 2-1. Phase I Performance Progress Schedule

Table 2-3. Contract Scope of Work

Task	Subject
C.2.1.	Perform the study of a remanufacturing system for replacing damaged vehicle parts under adverse conditions. Propose the repair of battlefield damaged critical parts for reducing downtime by fabricating equivalent parts (at the location of disability).
C.2.2.	Determine the feasibility of a field remanufacturing system. Determine the needs of the system for equipment and materials. Receive the details of parts subject to damage or failure for evaluation of processes (from CTR at request).
C.2.3.	Kickoff the contract of DAAE07-87-C-R064 Field Remanufacture of Army Parts to refine Phase I goals. Meeting the CTM of TACOM at Warren, MI for refining Army objectives.
C.2.4.	Review the details of existing Army vehicles for transport of remanufacturing system in repair shop size or retrieval (of failed parts) vehicles. Select the procedures of repair performance for experienced battalion level maintenance personnel.
C.2.5.	Collect the information of materials and parts for susceptibility to damage. Collect the information of parts for criticality rating. Define the possibility of rebuilding for a field condition environment.
C.2.6.	Investigate the design of selected parts for modification. Examine the possibility of material substitution for rebuilding. Determine the feasibility of remanufacturing the critical parts.
C.2.7.	Determine the processes available for part remanufacturing. Select the supplies and materials used for a field remanufacturing system.

Table 2-4. Partial List of Materials Reviewed

A. Technical Manuals:

BDAR - Battlefield Damage Assessment and Repair

1. For M113 Family of Vehicles
   Carrier, personnel, full-tracked, self-propelled

2. For M60 Tank

3. For M88 Recover Vehicle
   - 3A. Engineering Parts List - Equipment 8750301
   - 3B. Troop List eT 8750301
   - 3C Depot List eD 8750301

TM 9-2350-253-10, Section III, pages 55 - 73
- Maintenance Procedures TA 125202-125220
  - Adjusting Track Tension
  - Measuring Track Drive Sprocket Wear
  - Disconnecting Track
  - Connecting Track
  - Installing Track Link
  - Replacing Center Guide
  - Replacing Track Pad
  - Replacing Thrown Track
  - Refueling from Pressurized Source
  - Emergency Refueling
  - Isolating Fuel Tanks
- Basic Issue Items B10-B22 TA 125309-321

B. Prints

8750112, 3 sheets M-60A-1 Tank, Combat, Full-Tracked
F 8750301, 7 sheets M88 Medium/Recovery Vehicle Full-Tracked
K 10905405, 2 sheets Installation, Fuel Tank
K 10905415, 3 sheets M60E1 Medium Tank
- +Suspension Installation (Track Tensioning Procedure)
- +Suspension Installation (Other side)
- +Procedure for Inserting Torsion Bars

C. Assemblies and Other Structures

Capacitor and Housing	Base
Cover	Bulkhead Floor Plate
Disk	Fuel Tank
Housing	Hull
Hub and Arm	Hull Mounting Plate
Idler Arm and Wheel	Roadwheel
Roller	Suspension Weldment
Shock Absorber	Transmission Shroud
Turnlock	Turret

Table 2-4. Partial List of Materials Reviewed (continued)

D. General Parts

Adjusting Link	Drive Sprocket Hub	Lock Washer	Seal
Anchor	End Connector	Lock Wire	Shield
Bar	Filler Cover	Mounting Bolt	Snap Ring
Bolt	Fitting	Nut	Spring
Bracket	Gasket	Outrigger	Sprocket
Bumper	Grommet	Pad	Strap
Bushing	Ground Strap	Pin	Support Roller
Center Guide Cap	Headless Groove Pin	Plain Washer	Torsion Bar
Clamp	Hook	Plate	Transmission Guide
Clip	Hose	Plug	
Collar	Hub	Protector Cap	Valve
Cotter Pin	Link Pin	Puller	Washer
Dowel	Lock Pointer	Screw	Wedge
Drive Sprocket	Lock Ring	Screw Ring	Wedge Bolt

E. Related Items on M-88 Vehicle

Axe
Bolt Cutter
Crowbar
Link Pin Puller
Sledge Hammer - 10 lbs.
Snatch Block Torch Set - Med Duty (Acetylene and Oxygen)
Towing Cable
Track Connecting Fixture (with Bar Lever)
Utility Chain
Welders Goggles
Wire Rope Cutter

F. General Systems (from BDAR manuals)

Armor
Cooling
Communication
Electrical

Engine
- Air Intake
- Exhaust
- Lubrication
- Fuel
- Structure/Internal Component

Fuel Supply
Hydraulic
Powertrain/Steering
Track and Suspension

Listed in Table 2-4 are some of the specific technical manuals, items and part drawings which were initially reviewed in the Phase I study, so as to determine criticality to the operation of the vehicles. To start, approximately 50 assembly and detail drawings of various components in the M60 tank were provided to MRC by the contract technical monitor. In addition, BDAR technical manuals were provided for the M60, M113 and M88 tracked vehicles. The specific components or items of concern dealt primarily with track repair from battlefield damage and fuel system repair.

Models of the M113A1, M1 Abrams and M60A1 Bradley Tanks were made from 1/35th size parts and designs studied for determining the size requirements of the remanufacture equipment. This familiarization with the vehicles also allowed better understanding of the component assemblies and blueprints.

Phone calls, letter contacts, and a Defense Technical Information Center (DTIC) search were used to gather information on parts and component failures in certain U.S. Army tank and heavy duty vehicles.

The DTIC search abstracts divulged previous reports dealing with certain APG repair vehicles (track mounted in 1977 & 1987 and semi-trailor mounted in 1981). These reports dealt mainly with electrical failures and light repairs, including welding and field maintenance.

It was apparent that tank commanders, field sergeants, and APG personnel are the best sources for subjective field information. Army Maintenance System Analysis (AMSA) data bases are impersonal and at best limited to general replacement part groupings or cost accounting. Some information was garnered as to the frequency of failure but the critical parts MRC selected from other sources were not on the list. The AMSA data is obtained from peacetime experience based on normal operating failures. AMSA sent a tabulation of the M1, M2, M3 failed parts and this does not identify combat damaged parts. AMSA tabulates failure data by the loss of function approach (for examples: running gear damage of tank stops tank -- recover part and repair at a depot; engine damage prevents mission completion -- use cannibalization replacement by the next level maintenance crew; etc.).

Listed below are some major categories required for loss of function assessment:

- Ballistic Damage
  - Direct firing
  - Mines and fragmentation
  - Heavy artillery (scenario)
  - Indirect effects (Nuclear, Energy, Beams)

- Fatigue
  - Mechanical stress failure
  - Misuse by overworking and exceeding limits
  - Corrosion deterioration

- Inoperative
  - Neglect or loss
  - System failure
  - Lack of repair procedures
  - Terrain damage
  - Poor assembly
  - Negligent maintenance

- Environmental Damage
  - Weather
  - Aging
  - Corrosion

The Army also has computer records of parts with frequency of failure rates (FFR) for certain components located on tank vehicles; and MRC also reviewed the pertinent FFR data applicable to this program. The FFR criticality is determined by the type of failure damage. The tabulation does give an indication of which parts fail frequently but does not rate the importance to mobility.

The printouts also provide stockage provisioning codes, replacement time, and damage criteria. The heading FF IV indicates the failure factor and is the number of parts damaged per 100 end items per year. The part is listed by the National Standard Number (NSN) and nomenclature (part name). The heading SCMC describes the location for repair. The SMR code shows a letter Z for a throwaway (e.g., a grenade for launcher). Other code letters indicate a salvagable part or replacement.

This information did not indicate the combat damage of critical parts; however, selected parts having high rates FFIV are shown in Table 2-5.

After review of all of the above data from numerous sources MRC selected a few components which were common to all tracked vehicles and which were likely to be damaged in battle conditions such that the vehicle mobility and mission success would be jeopardized. In particular, one such item was the "Hub and Road Wheel Torsion Arm Assembly." MRC used a flowchart worksheet similar to that shown in Figure 2-2 to assist in selection of components and parts critical to tracked vehicle mobility. Figure 2-2 chart is somewhat analogous to a "fault tree" for tracked vehicle mobility; this approach was selected by MRC as the best approach for developing efficient field remanufacture techniques and establishing the level of feasibility of such field remanufacture, including behind enemy lines capabilities.

Table 2-5. Frequent Failure Data Summary for M1, M2, and M3 Systems

M1 Systems		
	GPS body assembly	206.5
	Resilient mount	165.8
	CX; NSN 5995, etc.	118.1
	Track shoe assembly	99.5
	Eye bracket	88
	Mounting bracket's	63
	GPS housing	41
	Brake assembly	42
	Mount	35
	Roadwheel	32
	Headed straight pin	24
	Angle bracket	24
	Armor plate	22
	Gun shield	22
	Turret seal	22
	Engine exhaust duct	20
	Metal tube assemblies	-
	Support roller	2
M2 Systems		
	Turret control	41
	Launcher assembly (firepower)	16
	Bent tube, metallic	31
	Shock absorber, direction action	39
	Radiator, engine cooling	29
	Track show, vehicular	265
	Wheel hub cap	48
	Fuel, engine, tank	109 & 158
	Spindle, idler support	3
	Arm assembly, idler	3
	Final drive assembly	24
	Transmission, crossover	46
	Housing, mechanical	22
	Hose assembly, nonmetal	26 & 13
	Sprocket wheel	44
	Solid rubber wheel	31 & 23
	Idler, outer and inner wheels	25 & 25
	Wheel, solid rubber tire	178
	Engine block assembly	14
M3 Systems		
	Track shoe, vehicular	70
	Wheel, solid rubber tire	30
	Tank, Fuel, Engine	46 & 92
	Radiator, Engine Cooling	45
	Wheel Hub Cap	11
	Transmission, Crossover	14
	Hose Assembly, Nonmetal	16

All systems and subsystems do not have to be tracked through the fault tree to see the critical damage item or pattern. Combat damage by ballistic, mine, or fire; or environment damage by weather or terrain; or damage by failure, neglect, and loss could effect any system. No remanufacturing capability could rebuild an entire tank in the field. However, this study is flexible in creating a unit for specific failure/damage that is usually reserved for the depot - using inventive and "standard maintenance procedures." Expedient recovery with this unit is simply the bridge between the remote breakdown site crew and the maintenance support group team using a transportable unit, by tracked, wheeled vehicles or airlift. After the expedient repair operation, the vehicle returns to a maintenance collection point for further evaluation. The flexible nature means only carrying the equipment and material necessary to effect this recovery. By defining the process of remanufacture the equipment is determined in advance and the appropriate repair system vehicle selected. It is not necessary to carry all remanufacturing capability equipment, tools and materials into every arena.

After identification and selection of the tracked vehicle mobility components as key items (see Figure 2-2), it was possible for MRC to identify modes of failure of key items. For instance the "Arm, Rear Road Wheel" (Part No. 10893555) has a necked down region which due to impact loading would provide a site for high stress concentration and possible failure. MRC performed a finite-element analysis on the above component to verify the potential failure region and subsequently a field repair "fix" was selected for the failed component. Details of this finite-element methodology are contained in paragraph 3.0 of this report. It was determined that an efficient field remanufacture "fix" would require drilling operations and use of novel high-strength, low-temperature composite materials. Based upon information of the above type, MRC, after consideration of all key vehicle components likely to be damaged in battle, selected the field repair equipment shown in Table 2-6 as the minimum necessary to achieve field remanufacture of tracked vehicle components.

After identification of failure modes, repair/remanufacture processes, and required tooling/remanufacture equipment, MRC investigated the methods for transporting the above to remote locations. MRC used existing Army transport vehicles wherever possible and the details of this selection are contained in par. 3.0. In particular, MRC analysis of the basic problem resulted in a concept of mobile repair units with remote roving subvehicles which could quickly transport the required repair or remanufacture equipment (loaded on skid pods) and materials from a heavy duty truck/trailer unit to even more remote sites. The above approach would allow for several tank-type vehicles to be repaired at the same time even though they may not be within a close radius of the heavy duty truck/trailer remanufacture unit. Details of these materials, components, and vehicles are covered in par. 3.0 of this report.

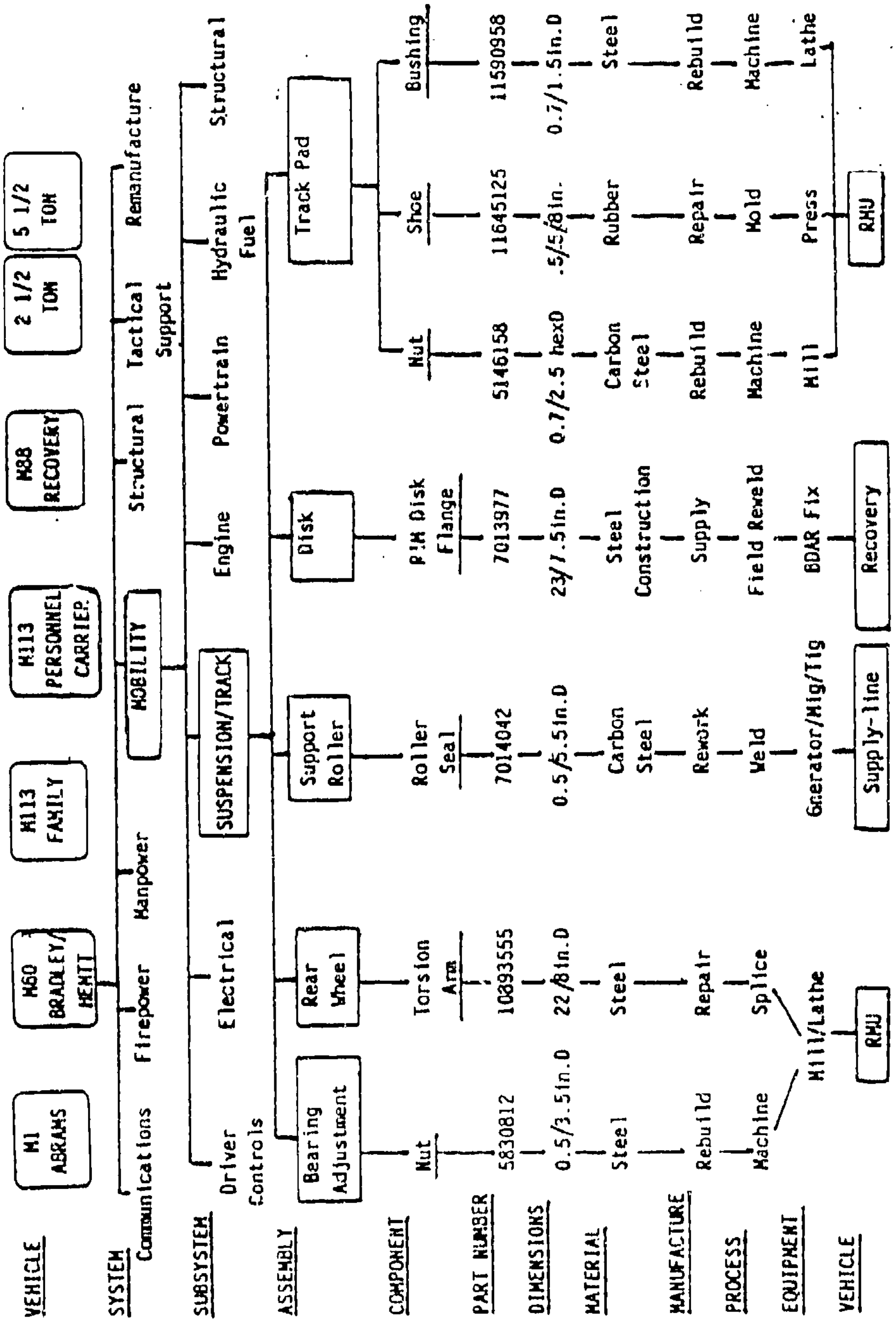


Figure 2-2. Fault Tree Flowchart

Table 2-6. Some Basic Field Remanufacture Equipment

Equipment	Manufacturing	Model No.	Description	Price, Dollar	Weight pound	Floor Space inch
1) Lathe	ENCO - Rutland Tool Supply	2642-0530	8" center lathe, compact 18" centers, 4.5" dia. Chuck - 1H.P. Motor, 110V, Single Phase	2,150.00	121	37"/20"
2) AC/DC Welder	Lincoln Electric Cleveland, OH		250 AC/DC - 7 kw (115/230V) 3.09 Perkins Diesel MiG-TiG			
a. Cutting Torch Generator		K-1330-CV	60 Hz	4,350.00	1010	61"/24"
b. Hi-Freq Unit		K-799	Hi-Freq TiG Component	53.00	--	--
3) AC/DC Welder Portable Unit	Miller Electric Appleton, Wisc.	AEAD-200LE	200 AC/DC; MiG-TiG	2,500.00	565	50"/24"
4) Mill/Drill	ENCO - 2330 S. Yale Santa Ana, CA	105-1110	Table Top - Variable Speed - 2 H.P., 110V R-8 Spindle, Single Phase	1,100.00	645	28"/20"
5) Cutting Saw	ENCO - 2330 S. Yale Santa Ana, CA	131-2014	14" Dia Steel, Stainless & Non-Ferrous Metal Cutting 3 H.P., 220V, Three-Phase	2,000.00	792	29"/36"
6) Heavy Duty Miscellaneous	Various Mfg.		Wrenches, Sockets, Crowbars	3,000.00	500	12"/30"

3.0. CONCLUSIONS

The findings obtained in the Phase I study are summarized in Table 3-1.

There are a number of Army tank parts susceptible to damage which would affect the mobility of the vehicle. Combat and environmental conditions cause components to fail. Benign use conditions can also lead to failure from effects such as fatigue failure of welds. After the vehicle commander identifies the damage, the critical parts are repaired at the depot. The tank is most often recovered by providing a part from another vehicle. Recovery of vehicle personnel is possible with strategic remanufacturing capability for remote site breakdowns (i.e., behind enemy lines).

Supply lines and depot repair maintenance are not always expedient in remote areas. The remanufacturing capability is most efficient when provided at or moved to the remote sites for returning the entire vehicle and crew to service or complete repair. Future Army battle scenarios could well include penetration behind enemy lines and the subsequent need for novel repair, remanufacture, and recovery systems.

Parts can be remanufactured at the breakdown site and/or substituted by design modification using portable machinist's equipment and a stock of specified materials including fiber/resin composites. A selected parts profile determines the equipment needed to fulfill the requirements. Normal conditions suggest spare parts for small critical components in supply storage.

Equipment and materials can be carried on existing and armor-modified vehicles. The field unit is limited to repairs performed using small remote rover units and equipment and materials carried on board with transportable skids. Figures 3-1 and 3-2 illustrate a schematic of a mobile remanufacture system with remote rover capabilities.

A remanufacturing prototype unit is feasible for on-site repairs to work in conjunction with standard Army repair and assessment field manuals (BDAR or vehicle) including rebuilding instructions or specifications.

3.1. Phase I Results - Task Descriptions

3.1.1. Technical Assessment. As noted previously in this report, the goals of the feasibility study were defined at the kickoff presentation held at TACOM in Warren, Michigan. It was found that the Army required flexibility in the project to address the current and developing concerns of battlefield parts repair, personnel protection and vehicle recovery. The vehicles, systems, and current procedures were identified and studied. It was concluded that by identifying the parts critical to mobility of vehicles and tabulating the frequently failed parts MRC could focus on the equipment and materials needed to remanufacture a few key parts. Track and suspension, fuel tank and lines were selected.

Table 3-1. Phase I Findings Summary

1. Modern Army vehicles contain critical parts or subassemblies susceptible to combat and environmental damage.

2. Failed parts are currently identified by vehicle commander and replaced by mechanics supply system.

3. Supply lines and depot repair maintenance are not always expedient in remote areas and are not designed to handle breakdown behind enemy lines.

4. Recovery of personnel with their vehicles is possible with a mobile field remanufacturing capability.

5. Parts can be remanufactured and/or substituted by design modification using transportable machinists equipment and novel materials.

6. Equipment and materials can be carried on existing and armor modified vehicles capable of providing rapid, remote (including behind enemy lines), remanufacture and repair capabilities.

7. A remanufacturing prototype unit is feasible for remote site repairs.

3.1.2. Vehicles and Parts Susceptible to Damage. Army vehicles, i.e., Army tanks in remote locations, can be demobilized during battlefield situations and conditions, and threaten personnel safety. Vehicle recovery can be difficult. Susceptible parts are located in the suspension, track, fuel, armor, communications, electrical, engine and drive train systems. These parts are damaged by ballistic, mine explosion, and other threats. Terrain and environmental damage can cause broken, corroded or vibration-loosened components and degraded welds at critical joints. Parts required for mobility are the first concern. These would include track and suspension, drive train and fuel systems. For purposes of demonstration in this Phase I feasibility study, the parts selected for review included the torsion and wheel arm assembly, pins, wedges and gaskets. Table 3-2 illustrates a "critical part tabulation" example generated for a road wheel torsion arm component on the M60 tank.

3.1.3. Remanufacture Equipment and Materials Selection. The equipment required for behind-enemy-lines part remanufacturing and machining, and the associated materials and supplies have been identified for Phase II acquisition. Table 3-3 provides a summary of remanufacturing equipment characteristics, uses and costs. Definition of equipment currently used for in-field repair was cataloged to prevent duplication, and to allow for efficient improvement of existing repair capabilities. A remanufacturing and remote repair system equipment cost table is included as a part of this section and also is demonstrated in the spreadsheet. These costs are from a general survey and are not additive due to some duplication. Repair materials have been investigated. Fiber/resin composites offer numerous repair advantages and dampen vibrations better than metal. With composites, directional stiffness and geometry/size effects can be tailored and the natural frequency of the part can be modified. Thermoplastics also have excellent shock and mechanical properties. These materials have lower costs and are easier to repair and recycle than thermosetting composites.

3.1.4. Remote Rover Vehicle for Transporting Remanufacture Unit. An investigation of the vehicles used in the Army arsenal revealed a number of possible mobile units. These units would be supplemented with smaller, quicker, and easier-to-move remote rovers designed for specific repair functions. The recommendation of a remote rover for torch and welding applications is an example. A specific welder/torch system unit for the rover vehicle weighs 500 lbs and is transportable with a generator capability. The generator can also be used as an emergency power source to warm components and to start the vehicles. The remote rover (RR) is capable of faster transport and hiding. Current Army vehicles can accommodate the remanufacturing unit with the use of special trailers. Shown in Figure 3-2 is the latest remote vehicle and field remanufacture system concept proposed by MRC in the Phase I Study. By having a dual-mobile capability (i.e., larger mobile transport system with smaller remote rover repair system) it is possible to handle two different repairs on two separate battle vehicles located apart from each other in a remote location.

Table 3-2. Critical Part Tabulation

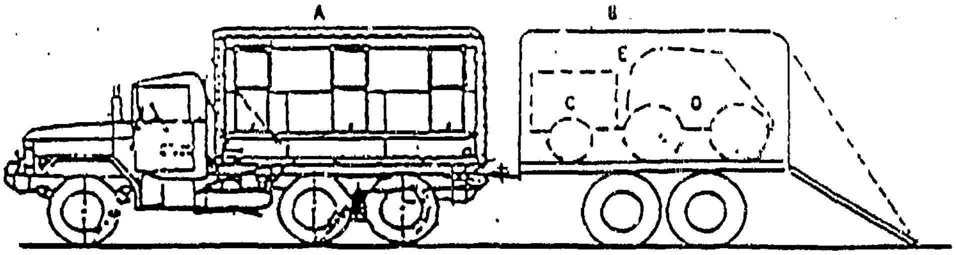
TABULATION					EVALUATION	
Part Name	Part #	Location	Failure Mode	Critical to Vehicle Mobility	Design	Modification
Arm	10893555	Road Wheel	Fracture	Yes	Bent Bar	Redesign/ Matl Subst
Spindle	799610	Wheel	Break	Yes	Rod	Material
T-Bar	-	-	Break	Yes	-	-
Shoe	-	Track	Wear	No	Pad	Remold
Screw	-	Hub	Stripped	Yes	Screw	Rethread
Sprocket	-	Hub	Wear	Yes	Tube	Material
Stud	Track	Roadwheel	Break	Yes	Rod	Material
Bolt	Hydraulic Linkage	Transmission	Wear	Yes	Rod	Material
Lever	Clutch	Gear Shift	Break	Yes	Rod	Material
Pin	Seat	Drivers	Break	Yes	Rod	Material
Screw	Steering	Adjusting Arm	Stripped	Yes	Screw	Rethread

Table 3-3. Remanufacturing Equipment Summary

PROCESS	EQUIPMENT	WEIGHT, LBS	SIZE, FT2	COST, $
Cutting	Lathe Tools	50	2	2,000.00
Cutting/Joining	Welder, MiG/TiG	500	8	2,500.00
Drilling	Drill Press/Mill	100	4	1,500.00
Electricity	Generator(see welder)	-	-	--
Heat Treating	Furnace	50	4	1,200.00
Machining	Lathe, Bench	300	12	3,500.00
Misc	Power Tools	50	5	1,500.00
Milling	End(see lathe,drill)	-	-	--
Sawing	Cutting Saw	10	5	800.00
Vacuum	Compressor/ Pump	200	9	2,000.00
Accessories	Connector,Cable,etc.	150	4	3,000.00
Transport	4-Track Rover	1250	24	4,000.00
Carrier	5 Mall Trailer	250	20	1,000.00
	TOTALS:	2910 lbs	108 sq ft	$ 23,000.00
	Max	8000 lbs	280 sq ft	$ 25,000.00

EQUIPMENT NOT INCLUDED IN CURRENT UNIT

Curing, Heat	Oven	50	4	1,000.00
Cutting	Lathe, Machinist	500	15	3,500.00
Filing	Lathe Tool	1	0.5	50.00
Forming	Pressing, Arbor	20	2	1,000.00
Grinding	Cutter Grinder	25	2	100.00
Heating	Hot Plate	5	0.5	1,200.00
Sawing	Band, Saw Table	80	5	1,200.00
Sawing	Vertical Saw	50	5	1,200.00
Shaping	Shaper	20	4	800.00



Mobile Transport System

A. 6 x 6, 2 1/2 ton, Military Truck (Van - Shop Type - #M109A3).

B. Trailer, 2 1/2 ton, Modified Military (Similar to Body Van Assembly #MIL-B-11315)

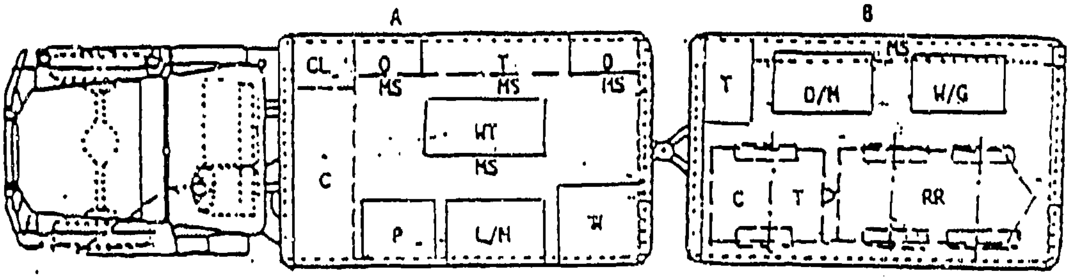
Remote Rover Sub-System

C. Cargo Trailer, 3/4 ton (Similar to MS 500069)

D. 4 x 4 Modified Off-road Vehicle

E. Option Replace Units C and D with a Modified Combined Unit Such as the 1.2 Ton, 4 x 4, Military Utility Truck #M274SA5 Up-graded to 1 ton.

Figure 3-1. Remanufacture Vehicle - External Diagram



A = Heated/Air Conditioned Work Area
C = Crew Bunks
CL = Crew Locker
O = Oven - Metal Heat Treatment
T = Tools - Tool Cabinets/Bench
O = Drill/Mill - Table Top
WT = Work Table, Vise, Hand Tools
W = AC/DC MIG-TIG Welder/Generator
L/M = Lath/Mill
P = Press
MS = Material Storage Under Benches, Etc.

B = Remote Rover Storage
RR = Remote Rover Vehicle
CT = Cargo Trailer
W/G = Movable (Skids) Welder
O/M = Movable (Skids) Drill/Mill
T = Tools
MS = Materials/Repair Stock

Figure 3-2. Remanufacture Vehicle - Internal Equipment Schematics

3.2. Feasibility of Battlefield Remanufacturing

A remanufacturing capability can be demonstrated with field use to show the flexibility and advantages of the units. The units can be transported to remote location sites to repair critical parts and return vehicle and personnel to temporary mission completion or permanent repair at the depot. Having an entire remanufacturing capability would require a large inventory, and materials selection, with unnecessary equipment movement. By focusing on the basic requirements of specific vehicle parts or situations a skid selection can be made at the depot and transferred to the appropriate vehicle through the use of the mobile remanufacture unit and the associated RR rapid repair subunits. Table 3-4 illustrates an outline for "Part Remanufacture" data to be used in battlefield remanufacturing scenarios.

3.3. Example of Battlefield Remanufacture Methodology

Numerous structural members are used to transmit bending forces from wheel units to torsion spring units on the tank track system. These connecting structural members, i.e., arms, are usually made of cast steel. The major stresses induced in these structural members are due to bending and torsional loads. In addition, the maximum stresses occur at the outer edges of the structural members. As such these members would be most efficient from a weight/strength standpoint if they could be fabricated in a hollow tube fashion. This would be analogous to an I-beam which carries the major stresses due to bending in the outer flanges. Thus, one approach for field remanufacture of damaged wheel arms would be to overwrap with a high-strength, lightweight graphite/epoxy composite material. Splinting would be used for a full break if clearance permitted.

MRC has experience with elastomer-modified and pulp-reinforced epoxy matrix systems with continuous graphite fiber. This has exhibited good shock impact and stiffness over a wide range of shock impact and high-stiffness characteristics, i.e., -75 to 220 ^{o}F. MRC developed these materials for an Office of Naval Research (ONR) study dealing with short cure times/low cure temperature needs as would be ideal in the field using heat lamps. The repair system is similar to repairing broken bones in the body. The lighter weight composite with hoop direction fibers over crisscross patterns would meet the requirements.

A finite-element stress analysis was performed on the M60 tank "wheel arm" component (i.e., Arm, Rear Road Wheel - part no. 10893555). Figure 3-3 illustrates a series of views indicating the "wheel-arm" critical part location, part design drawing, and associated finite-element model. The analysis was performed on an IBM personal computer (PC) using the COSMOS/M computer code. A total of 672 three-dimensional isoparametric solid elements, with 20 nodes per element were used to describe the "wheel-arm" component. Figures 3-4 and 3-5 illustrate, respectively, the top and side views of the components finite-element model after stress analysis.

A von Mises stress criteria was used to determine maximum compression and tension stress regions. A nominal load of 1,000 pounds was applied at the wheel axis position and the torsion spring end of the "wheel-arm" was assumed fixed for this hypothetical analysis. The finite-element stress levels at certain key locations were checked by means of basic strength of materials hand calculations and the results correlated well with each other.

Figure 3-6 illustrates a cross-section view of the "wheel-arm" finite-element model. A hypothetical transverse load, torque load, and bending moment load was applied to the "wheel-arm" component. The cross-section is composed of two semi-ellipses on a rectangular base. Equation 1 gives the equivalent geometric area moment of inertia, I_e, relationship for the cross-section of Figure 3-6.

$$I_e = \frac{BH^3}{12} + 2\,(I + AD^2) = 25.79 \text{ in.}^4 \qquad (1)$$

Where B is the width of the rectangular section, H is the height of the rectangular section, A is the area of the top and bottom semi-ellipses, I is the centroid area moments of inertia of each semi-ellipse, and D is the distance from the neutral axis up to the centroid of each semi-ellipse. The size and the geometry of the finite-element model of the "wheel-arm" were established from the detail drawing #10893555. The bending stress is:

$$\sigma_{bend} = \frac{MY}{I_e} \qquad (2)$$

Where M is the applied moment due to a hypothetical road shock load applied at the wheel centerline of the "wheel-arm" component, and the Y value is the distance from the neutral axis to the top of the semi-ellipse. The value of M is equal to 12,000 inch-pounds (1,000 pounds times a moment arm of 12.1 inches) and Y is the distance from the neutral axis to the outer surface.

The shear stress, τ, is calculated by considering the cross-section shown in Figure 3-5 to be an equivalent circular area and using equation 3:

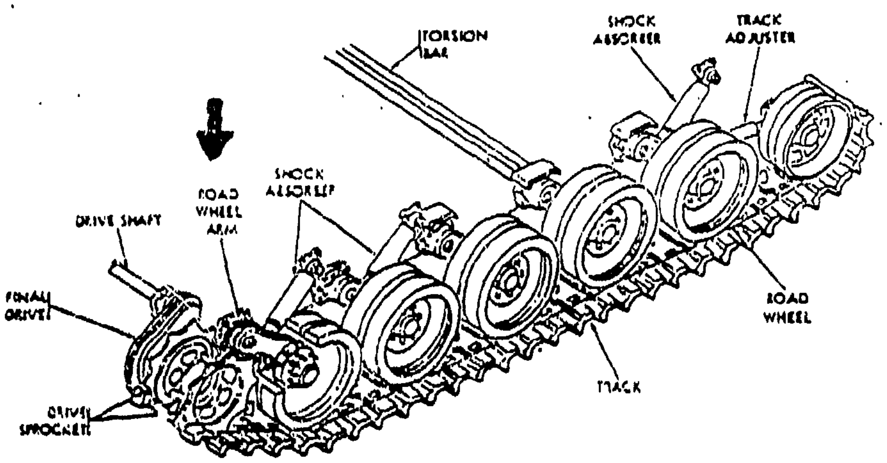
$$\tau = \frac{TR}{J} \qquad (3)$$

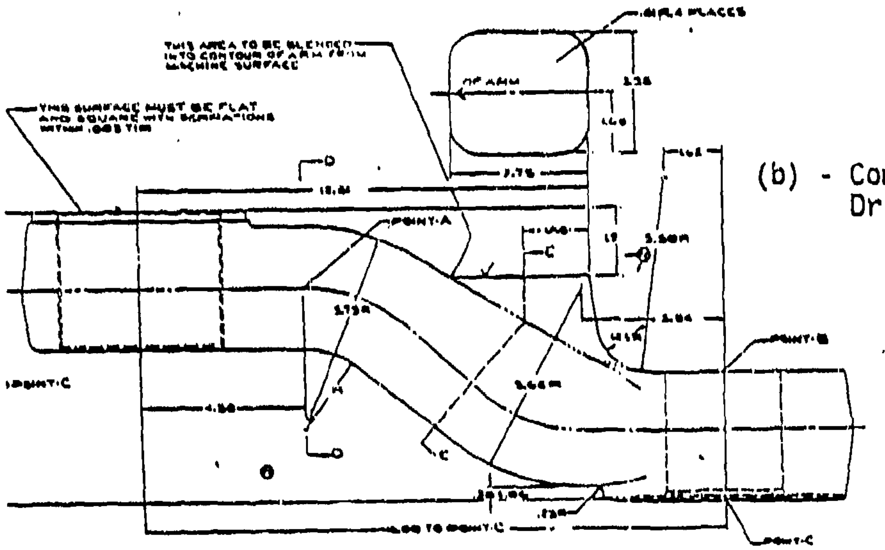
Where T is the torque (4,100 inch-pounds in this case), R is equivalent area radius (calculated to be 2.12 inches) and J is the equivalent area polar moment of inertia (calculated to be 31.53 in.^{4} in this example). The shear stress generated by equation 3 is 274 psi which compares reasonably well with the COSMOS finite-element shear stress prediction of 2 2 psi. The maximum bending stress calculated from equation 2 yields a value of 1,220 psi which also compares favorably with the maximum von Mises stress of 1,032 psi also predicted by the COSMOS code.

Table 3-4. Part Remanufacturing Equipment Requirements

	REMANUFACTURING ABILITY				EQUIPMENT REQUIREMENT					
Part	Repair Method	Type Material	$ Cost/lb	Hours Time	Repair Material	Equip. Required	cu ft Space	lbs Weight	$ Cost	Equip. Rating
Wheel Arm	Splice & Overwrap	Steel	4.00	4.0	Steel Pin & Composite	Drill Press Mill	4	100	1,500	1
Spindle	Machine	Steel	4.00	3.0	Steel Alloy	Lathe	12	800	3,500	2
T-Bar	Weld	Steel	4.00	2.0	Steel	Welder	8	500	2,500	1
Shoe	Cure	Rubber	2.00	1.0	Thermo-plastic	Oven	4	50	1,000	4
Screw	Machine	Steel	3.00	1.0	Steel	Lathe	12	800	3,500	2
Sprocket	Machine	Steel	4.00	2.0	Steel	Mill	4	100	1,500	1
Stud	Machine	Steel	3.00	2.0	Steel	Lathe	12	800	3,500	2
Bolt	Machine	Steel	3.00	2.0	Steel	Lathe	12	800	3,500	2
Lever	Machine	Steel	4.00	1.0	Steel	Lathe	12	800	3,500	2
Pin	Machine	Steel	3.00	2.0	Steel	Cutter	8	500	2,500	1
Screw	Machine	Steel	3.00	1.0	Steel	Lathe	12	800	3,500	2

(a) - Critical Component
(Roadwheel Arm)





(b) - Component Design
Drawing

(c) - Finite Element Model

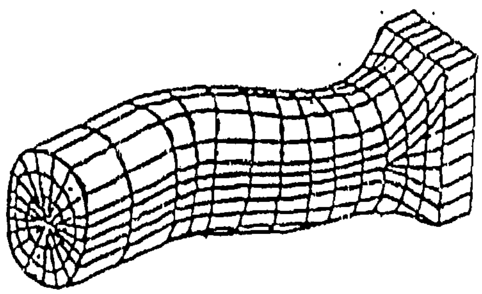


Figure 3-3. Redesign with Finite-Element Stress Analysis
of Tank Wheel Arm

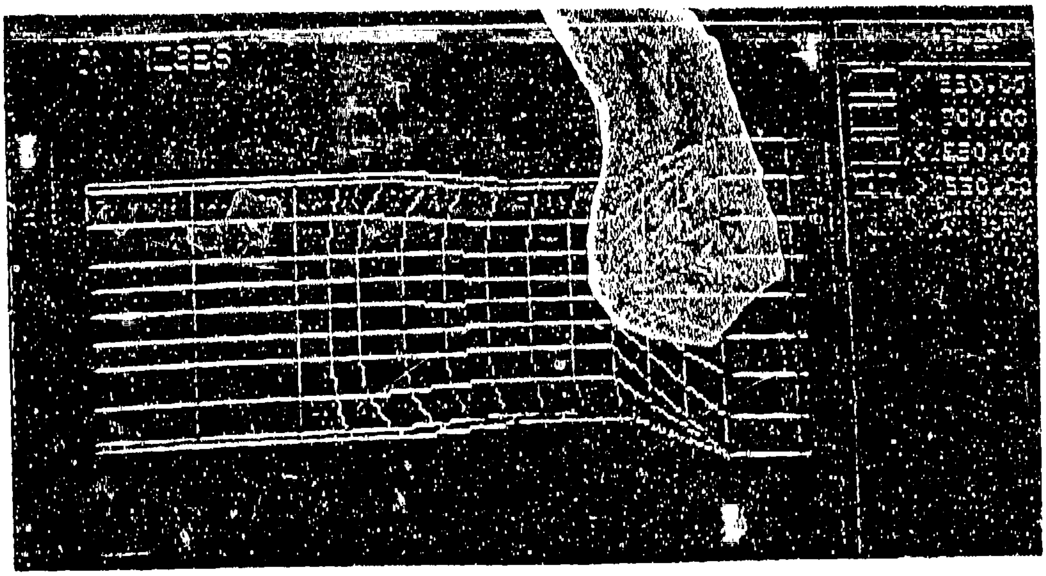


Figure 3-4. Top View of Finite-Element Stress Analysis of "Wheel-Arm" Component

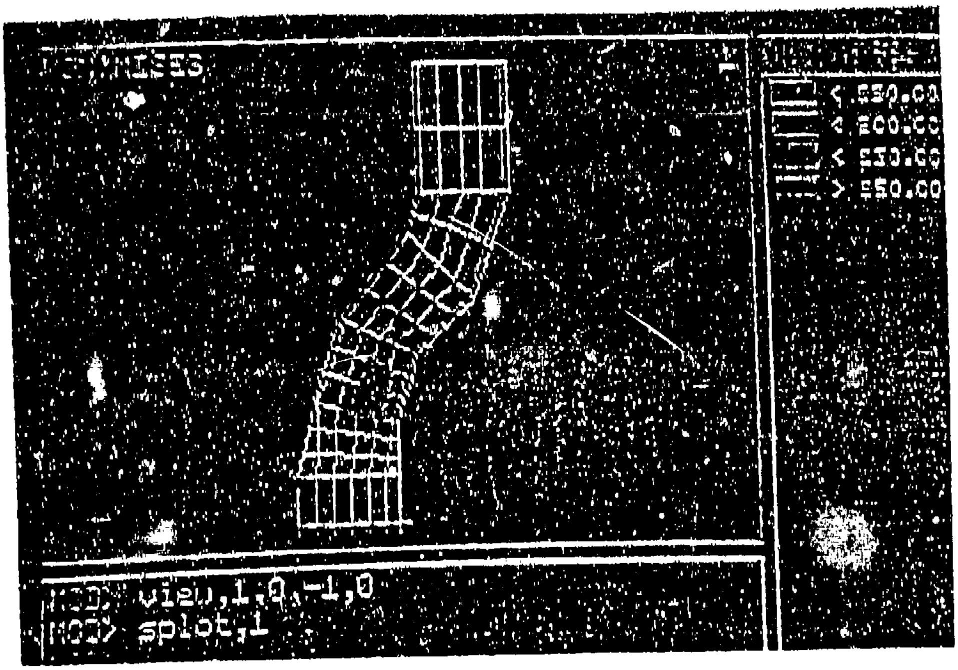
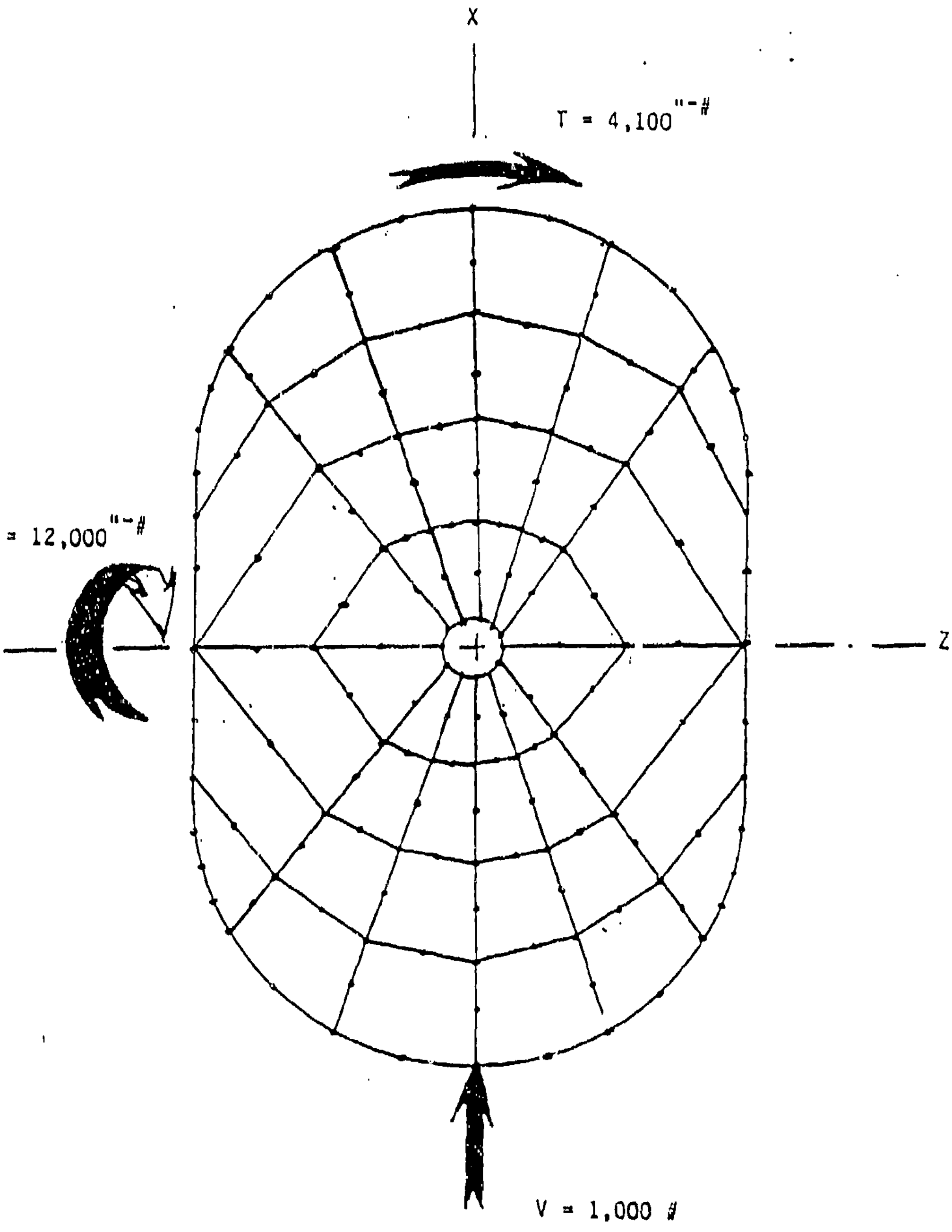
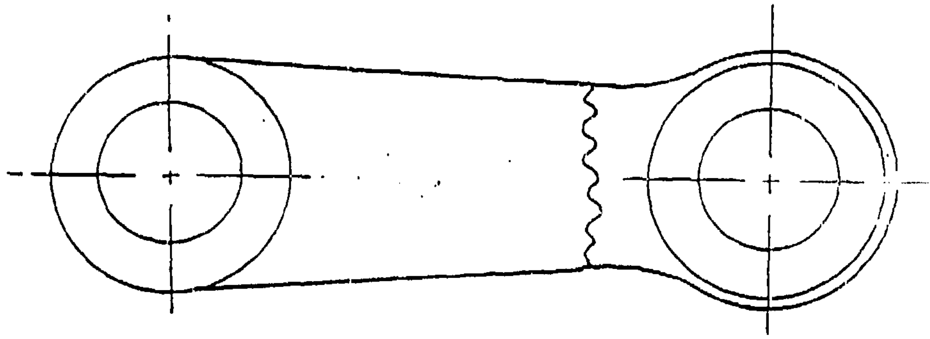


Figure 3-5. Side View of Finite-Element Stress Analysis of "Wheel-Arm" Component

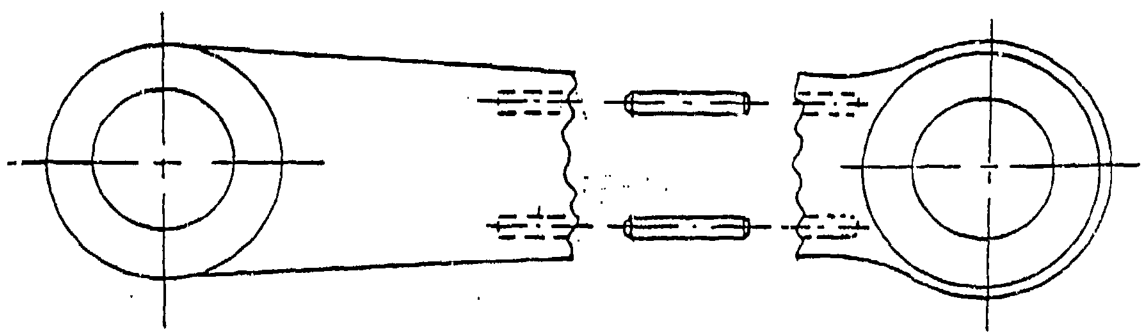


Section A-A

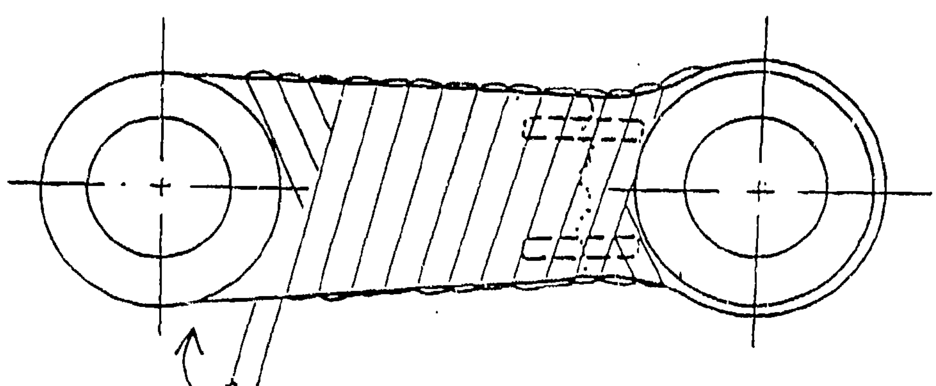
Figure 3-6. Hypothetical Loads on Finite-Element Cross-Section Model of "Wheel-Arm" Component



(a) - Fractured Critical Component - Wheel Arm.



(b) - Alignment Pins and Torque Load Transfer - Holes Drilled into Fracture Region.



(c) - Pre-preg Composite Overwrap for Bending and Axial Load Transfer.

Figure 3-7. Remanufacturing Example

Figure 3-7 illustrates a series of views which depict a "quick-fix" field remanufacture process for the failed wheel-arm unit. This methodology was developed in part of the Phase I tasks 4 and 5. In particular, the RR or the larger mobile transport unit could be used to drill and align the torque load transfer holes on the mating portions of the failed component. Heat-treat-hardened pins would be inserted, with epoxy potting and sealing compounds, into two drilled alignment and load transfer holes (i.e., the four holes would be drilled using a portable drill and alignment fixture carried either on a skid pallet with the remote rover unit or the tool system contained in the larger mobile transport repair unit). A high-strength pre-preg fiber/resin composite material would be over-wrapped on the irregular-shaped wheel-arm component in much the same way that a sprained ankle would be taped. The low-temperature, fast-curing resin system, examined by MRC in a previous ONR SBIR Phase I study, is contemplated as a candidate material for this situation. The resulting high-strength shell of the composite material can be tailored in thickness to carry bending and axial loads such that this unit would be functional for recovery to a fully equipped repair depot in friendly territory. The inserted pins would carry the torsional loading.

4.0. RECOMMENDATIONS

A three-phase developmental program is recommended as a solution to the problem addressed in this study. This program is broken down into the areas of: feasibility (i.e. Phase I currently being completed by MRC); development (Phase II currently being proposed by MRC); commercialization (future Phase III). A more detailed outline of the task areas associated with each phase of this program is given in Table 4-1. The Phase II objective is to develop and deliver a mobile remanufacturing capability unit for field repair of Army vehicles. Actual damaged, critical vehicle parts will be used to establish the optimum materials, equipment and processes needed to fit the remanufacturing unit on Army vehicles for transportation to remote locations. The Phase II proposed tasks are highlighted.

4.1. Recommended Technical Objectives

The technical objectives of the Phase II proposed effort are outlined in Table 4-2.

The results of the Phase I study will be used and applied to specific components to demonstrate the field use feasibility of the mobile remanufacture units. Actual damaged parts will be obtained from Army salvage or supply channels and analyzed for design and/or material modification. The process and equipment will be defined and acquired. The remanufacturing unit will be assembled and used on the critical parts. Process specifications for Army manuals will be written and service life determined by testing the remanufactured part to failure. Severe environmental protection and survivability, that is, armor for the repaired parts and transporting vehicles, will be designed.

Table 4-1. Outline of Recommended Three-Phase Plan

PHASE I - Feasibility of Remanufacturing Army Vehicle Parts.

1. Write a Technical Assessment and Presentation.
2. Determine Major Combat Vehicle Parts Susceptible to Battlefield Damage.
3. Review Blueprints to Determine Parts Critical to Mobility.
4. Demonstrate Design Modification and Material Substitution Methodology With Limited Analysis of a Critical Part.
5. Establish Processes and Methods for Remanufacturing.
6. Select Equipment Suitable for Field Remanufacture.
7. Select Vehicles to Transport Rebuild Capability.
8. Determine Feasibility of a Phase II Development Effort.

PHASE II - Development of Remanufacture Capability and Prototype Utilization.

1. Goals and Plans Definition.
2. Critical Parts Damage/Assessment.
3. Damage Review for Process Selection.
4. Remanufacturing Equipment/Materials/Supplies Acquisition.
5. Prototype Unit Construction.
6. Parts Specifications and Process Procedures.
7. Prototype Unit Part Fabrication Demonstration.
8. Armored Vehicle/Parts Designs.
9. Service Life of Parts and Equipment Study.
10. Results and Conclusions Reporting/ Phase III Feasibility.

PHASE III - Scale Up Design Transition of Remanufacturing Capability.

1. Scale Up Designs and Determine Production Costs for Army.
2. Determine Competitive Bid Suppliers for RMU's.
3. Transition Specifications to Army Field Manuals.

Table 4-2. Recommended Phase II Objectives

1. Define the Goals and Plans
2. Assess the Critical Parts Damaged in Exercise
3. Select Processes, Supplies and Equipment
4. Build Prototype Unit
5. Write Process Specifications
6. Demonstrate the Prototype
7. Design Protection and Determine Service Lives
8. Plan Phase III Commercial Venture

4.2. Recommended Technical Approach

The technical approach proposed in Phase II deals with systematically using the information on critical and frequently failed parts to develop the optimum remanufacturing capability. The undesirable toting of unneeded bulky equipment and supplies is rejected in favor of a novel mobile repair system. This is why the effort is directed toward the design of manageable-sized units capable of doing the essential tasks and using Army vehicles along with the RR.

4.3. Methods to Achieve Each Objective

4.3.1. Meeting with Agency. The goals and milestones will be clarified to provide a flexible program suited to remanufacturing capability, development needs and specific interests of the Army. Plans for achieving the objectives and program goals will be defined at these meetings by MRC.

4.3.2. Part Assessment. The parts critical to the mobility of the vehicles and Army missions will be accumulated and evaluated for design, materials, modifications and repair procedures. Finite element stress models will be made and used to investigate redesign possibilities.

4.3.3. Equipment. Potential basic supplies and processes will be assessed and used on the actual damaged parts, obtained from salvage, manufacturing and battlefield damaged vehicles, to determine the equipment best suited for remanufacture in this Phase II Effort.

4.3.4. Remanufacturing Prototype Unit. The most representative equipment accessories, and supplies will be assembled and a prototype transportable, self-contained (1-3 skids) unit will be built.

4.3.5. Process Specifications. Rebuilding and remanufacture/repair process instructions will be specified for use with the prototype unit relative to the selected damaged parts.

4.3.6. Prototype Unit Demonstration. Army mechanics will use the remanufacturing unit on various parts selected from actual failures. A field site application will be chosen for the demonstration near a troubled vehicle.

4.3.7. Part and Vehicle Service Life. Rebuilt or critical parts must be protected from additional damage. Additional care and design will provide the means for longer usefulness. The service life and likely damage modes will be determined for certain critical parts.

4.3.8. Phase II Commercialization. Plans for Army acquisition of remanufacturing units will be made by MRC and recommended commercial ventures. The assembled units will be flexible in design, equipment and rebuilding capabilities.

Wherever possible, existing Army components will be used so as to avoid costly duplication costs; however, due to certain unique requirements some portions of the remanufacture unit (i.e., remote rover system) may require MRC modified commercially available components.

5.0. DISCUSSION

5.1. Objectives Summary

The Phase II Program will use the tabulation procedures and technical information from the Phase I Final Report titled: "Remanufacturing Feasibility Study" to remanufacture parts with a prototype unit. To achieve this goal, task plans have been outlined and will include use of existing damaged parts or damaging of some critical parts; acquiring equipment, materials and supplies; constructing a transportable remanufacture unit; writing process methods for multimaterial and process remanufacturing using the remanufacture unit and methods; designing armor protection for critical part and remote rover vehicles; studying the maintenance and service life of equipment and remanufactured parts; and scaling up for Army purchasing of units.

5.2. Performance Schedule

Figure 5-1 shows the Phase II schedule with milestones including remanufacturing unit delivery and Quarterly Reports which are due 30 days after each 3-month technical effort.

5.3. Performance Tasks

5.3.1. Task 1 - Goals and Plans Definition. MRC and Army goals as outlined in the Phase II Proposal will be merged during an initial technical coordination meeting and implemented by initially securing damaged parts and components. A field exercise could produce critical failed part scenarios and demonstrate frequency of failures during battlefield conditions in simulated combat situations.

5.3.2. Task 2 - Critical Parts Damage and Assessment. Vehicle-damaged components will be assessed by analysis and testing studies. Observations by field commanders could locate mobility halts. Assessments by tank commanders would: locate parts critical to the operation of the vehicles; determine recovery of tank analyzed; assess current BDAR use and damage; determine when assembly was not repairable on the damaged vehicle; and determine when removal was not feasible. A specific remanufacturing need could be assessed and the damaged part submitted to MRC (or a facsimile). The quantity of parts must be documented but the damaged part delivery would be negotiated. More detailed analysis could be done on the most critical, or the most difficult part to obtain by supply channels and those which were not amenable to repair by BDAR methods (i.e., not included in current manuals). Finally, finite element analysis will be done on all critical parts to be assessed during the Phase II effort.

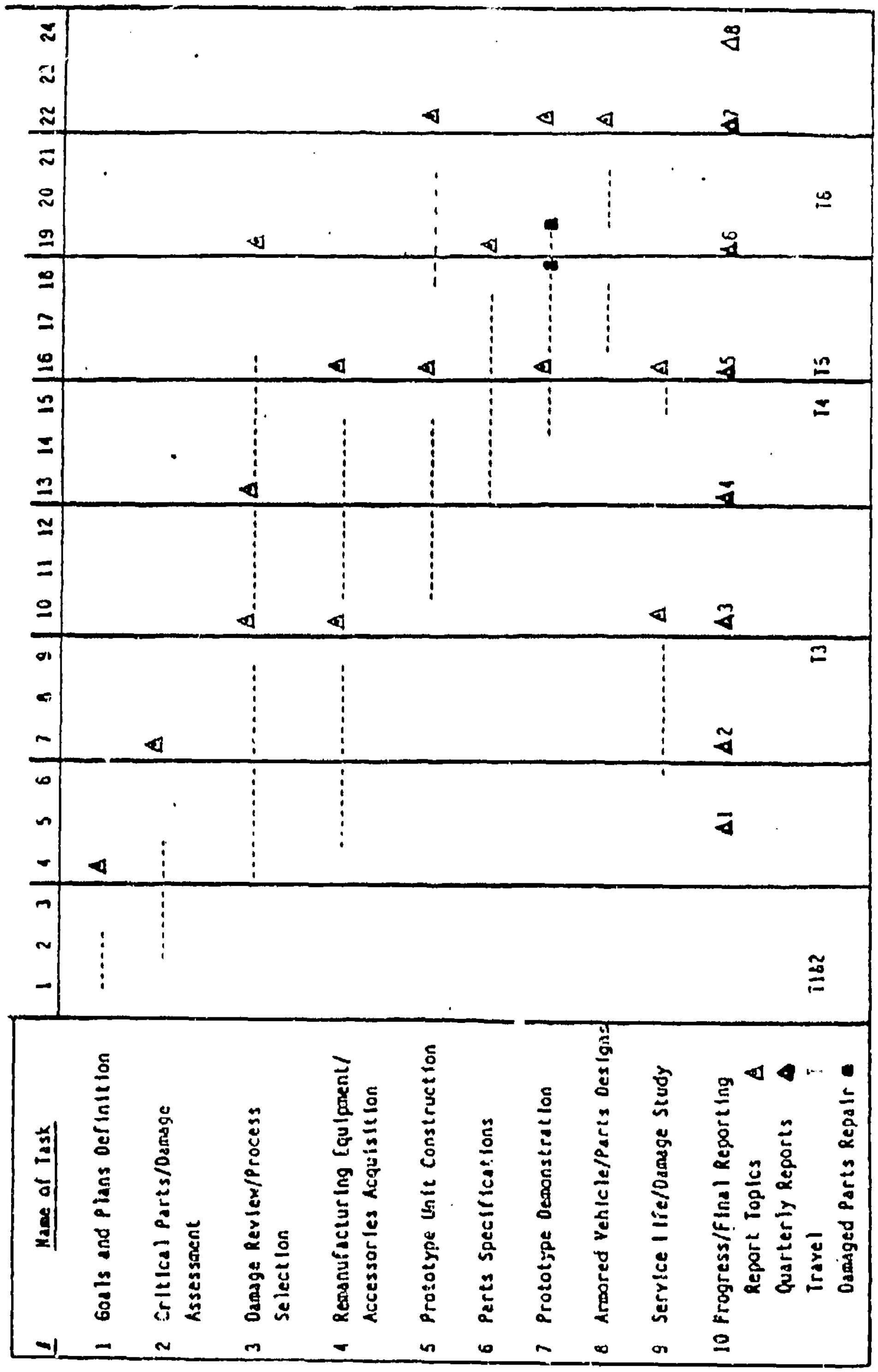


Figure 5-1. Phase II Performance Schedule and Milestones

5.3.3. Task 3 - Damage Review for Process Selection. A review of the field-damaged parts associated with ballistics, wear, misuse, and use will determine process, materials and equipment selection required for field remanufacturing to be accomplished. Questions of how the damage occurred will be answered by determining what effects the damage had on other systems and components, as well as how immediate the rebuilding could be accomplished.

5.3.4. Task 4 - Remanufacturing Capability Acquisition. Materials likely for use in remaking critical damaged parts will be acquired. This material may be purchased from scrap or may be obtained from damaged parts. Supplies and equipment will be purchased new and/or used for use in Task 5. This equipment is expected to include items such as the earlier specified welding equipment and certain composite materials (from Phase I Study). MRC will provide certain basic equipment requirements until MRC specified DoD equipment, defined by MRC, arrives at the MRC facility. All damaged and remanufactured parts will be Government-Furnished Property (GFP) and the equipment purchased by TACOM or MRC under this contract will be Government Property (GP) and governed by the Federal Acquisition Requlations (FAR).

5.3.5. Task 5 - Construct Prototype Unit. The equipment, supplies, and materials selected and acquired from Task 4 will be assembled and constructed into a complete unit and serve to demonstrate the prototype remanufacturing capability. A completely self-contained unit will be sent to the Army exercise arena for use in Task 7.

5.3.6. Task 6 - Process Specification and Remanufacturing. Parts and process specifications will be written for the redesign, modification, repair process, materials and equipment needed to remanufacture the potential damaged components or areas for Task 7 use.

5.3.7. Task 7 - Demonstrate Prototype. The delivered unit constructed in Task 5 will be used on actual damaged parts during adverse conditions following and using Task 6 process specifications. Consideration will be given to climate and terrain use variable. Those considerations will be in-line with current Army specifications.

5.3.8. Task 8 - Design Repair Vehicles/Parts Protection. An adaptable protection design which is lightweight will be proposed to allow enhanced survivability of parts and remanufacturing vehicle systems. Flexible shields, reactive coatings, barriers, or on site, composite, composite armored designs are suggested. Explosive armor feasibility will be investigated and evaluated. Personnel protection during battlefield conditions justify this design effort task.

5.3.9. Task 9 - Service Life Determination. Remanufactured parts, returned temporarily to combat situations are susceptible to damage at accelerated rates. These rates will be forecasted on monographs using computerized fault tree analysis for the parts assessed. (Protection systems will be analyzed for survivability and cost).

5.3.10. Task 10 - Deliverables (Travel, Progress and Final Reporting). The results/conclusions from each applicable Task will be included in Quarterly Reports. Travel will be made as required to select Army locals. A minimum of two trips will be made to TACOM, Warren, MI. Two trips to field sites are proposed to help in coordinating the technical and delivery efforts for part remanufacturing and equipment acquisition with the Contract Technical Monitor (CTM). Delivery of parts and Task 5 unit is included in this Task. A draft and Final Report will be made to report the conclusions and define the Phase III proposal effort.

5.4. Milestones and Reporting

The Phase II proposal has a number of items which are considered milestones. The first is the meeting with the agency to review the contract goals and objectives. The session will also help define the parts of interest and the method of coordinating the progress with the reporting so development of the unit is timely. The quarterly reports will help to manage the task efforts and will be planned accordingly. For example:

- Travel to kickoff and coordination meeting.
  Travel to Meppen, Germany Field Exercise Site.

- 2nd Quarterly Report, Technical Progress of:
  Damage review for processes, selection;
  Remanufacturing equipment, determination.

- 3rd Quarterly Report, Technical Progress of:
  Finite element results of damaged parts;
  Results of analysis of service life prediction.

- 4th Quarterly Report, Technical Progress of:
  Final processes selection;
  Final equipment selection and acquisition;
  Prototype remanufacturing unit description;

- Unit delivered.

- Travel to Meppen, Germany field site

- 5th Quarterly Report, Technical Progress of:
  Use of unit in field exercise;
  Parts remanufacturing specifications progress;
  Protection of damaged parts and vehicle progress;
  Final service life.

- 6th Quarterly Report, Technical Progress of:
  Final process specifications;
  Analysis of field remanufactured parts;
  Review of units capability.

- Travel to TACOM for performance reporting.

- 7th Quarterly Report, Final Technical Progress of:
  Phase II development draft;
  Unit capability modification and evaluation.

- 8th Quarterly Final Report;
  Phase III Proposal for production of Remanufacturing Units for Army Field use.

ADDENDUM

TITLE: ADDITIONAL LIST OF PARTS REVIEWED DURING PHASE I STUDY

	Part #	Part Name	Subsystem KEYSYSTEM
1	5146157	Lock	
2	5146158	Nut	
3	5146162	Ring, Lock	
4	5380812	Nut, Wheel Bearing Adjustment	TRACK WHEEL
5	5380856	Bolt, Hub	TRACK
6	5380881	Spacer, Wheel Arm	TRACK WHEEL
7	5602451	Retainer, Wheel Arm	TRACK WHEEL
8	6295380	Nut, Arm Bearing, Retaining	TRACK
9	6295383	Washer, Arm Bearing, Retaining	TRACK
10	6295385	Guard, Arm-Bearing Seal	TRACK
11	7013976	Disc, Road Wheel, Complete	TRACK Assembly
12	7013977	Disc, Road, and Idler Wheel Welded Construction	TRACK Assembly
13	7013978	Flange, Road and Idler Wheel	TRACK
14	7013979	Disc, Road and Idler Wheel	TRACK
15	7014011	Anchor, Torsion Bar	SUSPENSION
16	7014042	Guard, Support Roller Seal	TRACK
17	7058072	Rim, Road and Idler Wheel	TRACK
18	7060078	Pin, Spring	
19	7070078	Pin, Spring	
20	7359890	See 7359891	
21	7359891	Spring, Torsion Bar, Suspension	SUSPENSION
22	7364248	Hub, Road Wheel	TRACK
23	7364254	Cap, Hub	TRACK
24	7364260	Hub, Road Wheel	TRACK Assembly
25	7364672	Seal	Assembly
26	7379007	Spring	
27	7720553	Spacer, Bearing	
28	7760336	Procedure	Assembly
29	7953753	Support Roller	TRACK Housing
30	7953877	Support Roller	TRACK Housing
31	7953933	Hub and Arm	TRACK Housing
32	7997607	Spacer	
33	7997610	Spindle, Wheel	TRACK WHEEL
34	8346930	Cup Drive, Bushing & Mounting	
35	8364404	Pin, Dowel	
36	8370079	Spring, Volute	Assembly
37	8376364	Seal, Oil (Retainer)	
38	8387092	Gasket	
39	8387093	Gasket	
40	8461416	Bearing, Roller, Needle	
41	8698076	Shield	
42	8706067	Wheel, Welded Construction	TRACK WHEEL
43	8721602	Drive Key	

ADDITIONAL PARTS (continued)

44	8750112	TANK, Combat, M60A1, Full-Tracked	
45	8750301	RECOVERY VEHICLE, M88, Medium, Full Tracked	
		Front Elevation	
		Equipment List, EPL	
		Troop List	
		Depot List	
46	8762153	Spacer, Axle	TRACK
47	8762154	Axle, Track Support	TRACK
48	8762155	Axle, Track Support	TRACK
49	8762156	Axle, Track Support	TRACK, Assembly
50	8762157	Axle, Track Support	TRACK, Assembly
51	8762180	Torsion Bar Support	SUSPENSION, Housing
52	8762477	Support Roller	TRACK, Housing
53	8762543	Cap, Wheel Hub	Wheel, Assembly
54	8763023	Hub, Wheel	Wheel, Assembly
55	10867401	Water Sealing, Diagram	
56	10887503	Bracket, Shock Absorber (Lower Rear)	SUSPENSION
57	10893555	Arm, Rear, Road Wheel	TRACK, Wheel
58	10905405	Installation, Fuel Tank	FUEL TANK
59	10905415	TANK, Medium, M60E1	
		Track Tensioning	Procedure
		Suspension Installation	
		Inserting Torsion Bars	Procedure
60	10905985	Arm	Assembly
61	10915601	Suspension Weldment	
62	11590958	Bushing, Sleeve	
63	11599975	Track	TRACK, Procedure
64	11599977	Track Installation on Vehicle	" Procedure
65	11645124	Track, T-142 (80 Shoe section)	" Assembly
66	11645125	Shoe, Track T-142	" Assembly
67	11645792	Shock Absorber, Direct Action	SUSPENSION
68	11655771	Washer, Lock	
69	11674567	Hub and Arm	Assembly
70	12251859	Wheel and Hub	Assembly
71	12251861	Roller	Assembly
72	12251872	Roller	Assembly
73	12257551	See 12257551 Track	Assembly
74	12270877	Chassis	Assembly
75	12270997	Seal, Double Lip	
76	12273103	Race, Bearing, Inner	
77	12291303	Bracket	

ADDITIONAL LIST (continued) - VEHICLE CHARACTERISTICS

Military Standard/Design

MS- 52112	M559	Truck, Tank, Fuel Servicing 2500 Gallon, Amphibious, Inland Water
52113(AT)	M553	Truck, Wrecker, 10 ton,
52167(AT)	M561	Truck, Cargo, 1 1/4 ton, 6220 sqin Aluminum Alloy Frame
53085	M101A1	Trailer, Cargo, 3/4 ton, 2 wheel
53088	M55	Truck, Cargo, 5 ton, 215" wheelbase
500001	M172A1	Semitrailer, Lowbed, 25 ton, 4 wheel
500010	M51	Truck, Dump, 5 ton, 6x6
500013	M105A2	Trailer, Cargo: 1 1/2 ton, 2 wheel
500015	M45A2	Chassis, Truck: Multifuel Engine, 2 1/2 ton
500018	M139	Chassis, Truck: 5 ton, 215" wheelbase
500036	M448	Trailer, Van: Shop, Folding side, 1 1/2 ton
500052	M274A5	Truck, Platform, Utility: 1/2 ton, 4x4
500067(AT)	M348A2D	Semitrailer, Van: Electronic, 26 ft, 2 wheel
500068	M49A2C	Truck, Tank: Fuel Servicing, 2 1/2 ton,
500069	M416	Trailer, Cargo: 1/4 ton, 2 wheel
500071	M151A1	Truck, Utility, 1/4 ton, 135" wheelbase
500076	M46A2C	Chassis, Truck: Multifuel Engine, 2 1/2 ton, 190" wheelbase
500078	M492	Chassis, Truck: 1 1/2 ton, 2 wheel
500080	M36A2	Truck, Cargo: Multifuel Engine, 2 1/2 ton,
500081	M354	Dolly, Trailer Converter, 15 ton, 4 wheel
500082(AT)	M348A2H	Semitrailer, Van: Electronic, 26 foot, 2 wheel
500085	M109A3	Truck, Van: Shop Type, 2 1/2 ton,
-1		8736570 with winch
-2		8736569 less winch

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